Methods to measure infant exposure to environmental tobacco smoke (ETS) are needed to identify infants at highest risk for ETS-related health problems. The purpose of this study was to validate measures sensitive to changes in levels of infant exposure to ETS and to develop a predictive model of infant exposure to ETS. Fifteen infants of smoking mothers were followed from birth to 6 weeks of age. Exposure to ETS was measured by using a smoking habits questionnaire, cigarette "butt" collection, infant urine nicotine and cotinine levels, and ambient nicotine (personal air monitors).

The 24-hour cigarette butt collection was the best predictor of acute (adjusted $r^2 = .83$) and chronic exposure (adjusted $r^2 = .47$) measured by infant urinary nicotine and cotinine levels when the infants were 2 weeks of age. Including scores on the smoking habits questionnaire and ambient nicotine levels increased the adjusted r^2 to .88 and .61, respectively.

Measuring Infant Exposure to Environmental Tobacco Smoke

MARY BETH FLANDERS STEPANS
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University of South Carolina

Exposure to environmental tobacco smoke (ETS) poses a significant risk to the health of children (Couriel, 1994; Gergen, Fowler, Maurer, Davis, & Overpeck, 1998; U.S. Environmental Protection Agency [EPA], 1992). This risk becomes even more significant in light of the fact that in the United States, 42% of children under age 5 live in households with adults who smoke

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(Overpeck & Moss, 1991). Aligne and Stoddard (1997) estimated that parental smoking results in yearly medical expenditures for children of $4.6 billion. Because the mother's smoking pattern is highly related to the child's exposure (EPA, 1992), the logical way to reduce a child's exposure to ETS is for the mother to quit smoking (Greenberg et al., 1989). Despite national campaigns, smoking cessation programs have not been as successful for women as for men (Centers for Disease Control and Prevention, 1994; Escobedo & Peddicord, 1996; Windsor et al., 1993). Until women successfully stop smoking, methods must be devised to help nurses identify infants at highest risk for ETS-related health problems. Sensitive measurement of nursing outcomes is a critical issue for nursing research (Hinshaw, 1991; Stewart & Archbold, 1992, 1993). Before nursing outcomes can be measured, a sensitive model for prediction must be identified. In terms of infant exposure to ETS, this process should lead to a method of identifying those infants at most risk for health problems related to exposure to ETS. In addition, outcome measures that are sensitive to change in the levels of exposure to ETS are the key to determining the successful evaluation of nursing interventions designed to protect the infant from exposure to ETS.

PURPOSE

To address the problem of infant exposure to ETS, this study aimed to: (a) develop a model derived from maternal (smoking behaviors) and environmental (ambient nicotine) variables that predicts acute and chronic infant exposure to ETS (measured by infant urinary nicotine and cotinine): and (b) evaluate the concurrent validity of personal air monitors, cigarette "butt" collection, and smoking history in documenting exposure to ETS as measured by infant urine cotinine.

REVIEW OF LITERATURE

Thirteen percent of the mothers who delivered babies in 1996 reported that they smoked (Mathews, 1998). These young smokers not only place themselves at risk but also jeopardize the health of their infants. The effects of exposure to ETS and

methods used to measure exposure and absorption are explored in this article.

ENVIRONMENTAL TOBACCO SMOKE

Cigarette smoke contains thousands of elements comprising more than 4,000 substances (Henningfield, 1986). The effects of ETS on DNA, bronchial mucosa, macrophages, oxygenation, and the sympathoadrenal system in adults led to speculation about ETS exposure as a cause of health problems in children. Parental smoking is associated with sudden infant death syndrome, respiratory syncytial virus bronchiolitis, acute otitis media, otitis media with effusion, and asthma (Aligne & Stoddard, 1997). Bakoula et al. (1995) used the presence of urinary cotinine (a nicotine metabolite) to conclude that children exposed to ETS were 3.5 times more likely to have respiratory problems than nonexposed children. In addition, families must cope with increased health care costs stemming from the need for medical therapy and emergency department visits (Cunningham, O'Connor, Dockery, & Speizer, 1996; Stoddard & Gray, 1997). Aligne and Stoddard (1997) estimated that parental smoking "results in annual direct medical expenditures of $4.6 billion and loss of life costs of $8.2 billion" (p. 648).

MEASUREMENT OF EXPOSURE TO AND ABSORPTION OF ETS

Exposure to ETS is difficult to measure (Kawachi & Colditz, 1996). Methods to quantify infant exposure to ETS include parental reports of smoking habit via questionnaire (Greenberg et al., 1989; Woodward, Owen, Grgurinovich, Griffith, & Linke, 1987) and air sampling for nicotine and respirable suspended particle mass concentrations (Marbury, Hammond, & Haley, 1990, cited in EPA, 1992). More direct assessment of absorption of ETS involves the measurement of nicotine and its major metabolite, cotinine, in infant serum (Etzel, Pattishall, Haley, Fletcher, & Henderson, 1992; Luck & Nau, 1985), hair (Pinchini, Altieri, Pellegrini, Pacifici, & Zuccaro, 1997), and urine (Bauman, Strecher, Greenberg, & Haley, 1989; Greenberg et al., 1989; Labrecque, Marcoux, Weber, Fabia, & Ferron, 1989; Luck & Nau, 1985). Although some authors advocate using a combination of questionnaires and biologic measures

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to evaluate exposure to ETS, there is no agreement on which combination provides the most accurate picture of exposure (Kawachi & Colditz, 1996).

The usefulness of questionnaires is limited in assessing exposure to ETS (Marbury, Hammond, & Haley, 1993). One must depend entirely on the participant's ability to recall smoking behavior. In assessing infant exposure to ETS, the mother's ability to recall as well as her willingness to report her smoking behavior may be influenced not only by how busy she is, but also by the negative implications of exposing one's infant to cigarette smoke. In addition, personal exposure depends not only on how many cigarettes are smoked but also on room size, room air exchange rates, and adsorption of ETS onto room surfaces (Marbury et al., 1993). In spite of these limitations, Greenberg et al. (1989) concluded that the number of cigarettes the mother reported smoking per day was highly correlated to the infant's urinary cotinine level (.54), whereas Chilmonczyk et al. (1990) found a modest correlation (.39). Although collection of urine samples is much more practical than obtaining serum samples, collection of infant urine can be problematic. Marbury et al. (1993) were unsuccessful in collecting urine samples 20% of the time in children under 2 years of age.

Personal monitoring systems show promise because they provide a more direct measure of an individual's exposure to ETS (Coultas, Samet, McCarthy, & Spengler, 1990a, 1990b; EPA, 1992; Hammond, Leaderer, Roche, & Schenker, 1987; Marbury et al., 1993; Spengler, Treitman, Tosteson, Mage, & Soczek, 1985). Personal air monitors are lightweight devices that can be clipped to clothing. The monitor works by passive diffusion of air containing nicotine through a filter. Of the 10 studies of personal air monitors presented in the EPA's 1992 report, only two were conducted in the home. Only Marbury et al. (1993) documented children's exposure to ETS using the personal passive monitoring system. These authors concluded that preliminary studies must be done to design an adequate exposure assessment strategy because "one strategy may not be appropriate for all environments" (p. 1097).

There is strong agreement in the literature about the significant risk that passive smoking poses to infants, although there is no agreement on which method or combination of methods

provides the most accurate assessment of level of exposure and absorption of ETS products. Development of a predictive model for infant exposure to ETS would identify infants in greatest need for nursing intervention to lower their exposure. Validation of research measurements of ETS exposure advances nursing science as clinical intervention programs are developed.

METHODS

RESEARCH DESIGN

A longitudinal passive observational design was used. This study was approved by the Institutional Review Boards of the University of South Carolina, University of Wyoming, Ivinson Memorial Hospital in Laramie, Wyoming, and United Medical Center in Cheyenne, Wyoming.

POPULATION AND SAMPLE

The newborns enrolled in the study were born to women who smoke (N = 15) in the western region of the United States at an altitude of more than 7,000 feet. Eligibility criteria for infant participation were as follows: Infants must have been born in a hospital, been at least 37 weeks gestational age (according to the Ballard scale), weighed at least 2,268 grams (5 pounds) at birth, been discharged from the hospital on the same day as their mothers, been on oxygen for no more than 24 hours after birth, have had a total bilirubin of less than 15 mg/dl in the first week of life, been bottlefed, and have no significant postnatal problems. Mothers were eligible if they experienced no significant health problems and were discharged with their infants. Mothers were classified as "smoking" if they smoked five or more cigarettes per day. Participants were recruited by personal interviews on postpartum units. Breastfed infants were excluded because the focus of the study was on environmental exposure to ETS, and nicotine in the mother is transferred to breast milk (Luck & Nau, 1987; Stepans & Wilkerson, 1993).

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INSTRUMENTATION

Maternal smoking history. The mother's smoking history was collected by asking the mother how many cigarettes she smoked per day, the number of other smokers in the household, as well as the infant's proximity to her when she smoked. A composite score yielding interval data was attained by adding together all numerical responses and proximity responses. The questions about the infant's proximity to the mother when she smoked were handled in the following manner: A weight of 20 was given both to the response that the mother smoked in the house and to the response that she usually smoked while feeding the infant; a weight of 10 was given to the response that the mother sometimes smoked while feeding the infant, to the response that the infant slept in the living room during the day rather than in a bedroom, and to the response that the mother smoked in the same room with the infant; a zero was given to those responses indicating that the mother never smoked during the infant's feeding, never smoked in the same room with the infant, smoked outside, and placed the infant in a bedroom during the day to sleep.

The questionnaire was evaluated for reading level using RightWriter (1987), version 2.1 and found to be at grade level seven. After review by four experts in nursing research and a small pilot study, the questionnaire was found to have face validity in that it reflected maternal smoking behavior and provided information about the conditions in which the infant was exposed to ETS. The questionnaires were pilot-tested to determine clarity and time required for completion.

Cigarette butt. A 24-hour collection of cigarette butts (residual ends) was obtained by asking the smoking mothers to use a reservoir constructed of an empty 12-ounce soda can decorated with attractive paper. Mothers were given the "ashtray" at the initial visit and reminded by phone to begin the 24-hour collection the day prior to the scheduled visit. The mothers were encouraged to place the cigarette butts in the reservoir after each episode of smoking. The contents of the ashtray were collected by the researcher during the home visits.

Ambient nicotine. Ambient nicotine levels were measured with the personal passive air monitor (PPAM). The PPAM is held within a 37-mm polystyrene cassette (Marbury et al., 1993) and functions without a power source. The PPAM was placed within 3 feet of the infant's face on the crib or infant seat unless there were other small children in the household. In those cases, the monitor was hung as close to where the infant slept during the day, but out of the reach of other small children. PPAMs were placed in the home when the infant was discharged from the hospital and replaced every 2 weeks until the infants were 6 weeks old.

Capillary gas-liquid chromatographic assay was used to determine the levels of nicotine in the air collected with the PPAMs. Analysis of ambient nicotine was directed by Brian Leaderer at the John B. Pierce Laboratory and Department of Epidemiology and Public Health, Yale University School of Medicine, New Haven, Connecticut. The lower detection limit of the monitor has been found to be 0.01 micrograms of nicotine, and the coefficient of variation is 0.11 (O'Connor, Holford, Leaderer, Hammond, & Bracken, 1995). The levels of ambient nicotine were calculated to reflect average daily exposure.

Urine nicotine and cotinine. Urine was collected by placing two cotton balls in the diaper close to the urethral opening. The urine was squeezed out of the cotton balls and placed in a test tube to be frozen. Urine samples were placed in polypropylene plastic containers and frozen at −25°C.

Nicotine is a measure of acute exposure to ETS, and cotinine measures chronic exposure to ETS. A Model 5890A Hewlett-Packard gas chromatograph equipped with a nitrogen phosphorus detector and a 10m × 0.53mm cross-linked fused-silica capillary column inlet system was used for analysis of urine samples. A model 3393A Hewlett-Packard integrator was used for peak area counts. Analysis was done by the investigator through the laboratories of the School of Pharmacy at the University of Wyoming. Statistical analysis of the calibration curve revealed an adjusted r^2 of .98 for cotinine before and after freezing the samples. Because all the infant urine samples were frozen, the regression equation based on analysis of the frozen samples was used.

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RESUL

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The analyses of the calibration curves for nicotine revealed an adjusted r^2 of .96 before the samples were frozen, but −.15 after the samples were frozen. It became obvious that freezing the urine samples adversely affected the nicotine molecule. The decision was made to use the regression equation to predict values before freezing.

Because the quantity of urine was different for each collection, creatinine concentration was determined using the Abbott Vision Proclaim System. Results were expressed as a cotinine to creatinine ratio or nicotine to creatinine ratio.

DATA COLLECTION

After eligibility was determined using a solicitation guide and written informed consent was obtained, baseline data were collected in the hospital by the investigator. Data were collected in the homes of the mother-infant pairs at 2, 4, and 6 weeks after delivery. Anecdotal notes about circumstances related to maternal smoking behaviors were taken by the researcher as data were collected.

DATA ANALYSIS

Regression analysis and trend analysis were used in this study. The level of significance was set at 0.05 using the Bonferroni adjustment to control for Type I error (Marascuilo & Serlin, 1988). This control is crucial because the same sample was used for all analyses, and the variables are related to one another.

RESULTS

DESCRIPTION OF POPULATION AND SAMPLE

The women in this sample averaged 22 years of age, 11.4 years of formal education, and had an average household yearly income between $10,000 and $19,000. Fewer than half—47%—were married. The mean birth weight of the infants

was 2,999.5 grams, gestational age was 38.67 weeks, and Apgar scores at 1 and 5 minutes were 7.93 and 9.0, respectively. None of the mothers fed foods to their infants known to contain nicotine. All participants in this study were Caucasian. This is a reflection of extremely limited ethnic diversity in southeastern Wyoming [(94% Caucasian) (Jackson Hole Visitors' Guide, 1998)], where data were collected.

All smoking mothers who enrolled in the study also smoked during pregnancy. The number of cigarettes smoked per day did not increase significantly from an average of 12 per day at the time of delivery to 13 per day at 6 weeks postpartum . Most smoking behaviors as they related to the infants changed only slightly over time. None of the smoking mothers reported smoking while feeding their infants at the time of birth, and only 1 out of the 15 did so by the time the infant was 6 weeks of age. Six of the mothers planned to smoke in the presence of the infant at the time of delivery, and 7 reported doing so by the end of the 6 weeks. Most mothers (10) intended to have the babies sleep in the bedroom during the day, but 10 out of 15 infants slept in the living room during the day by the time they were 6 weeks old.

Cotinine and nicotine levels in the urine of infants of smoking mothers are represented in Table 1. The standard deviation of the cotinine levels was exceptionally high (1032.96) when the infants were 4 weeks of age due to an outlier. One infant had a cotinine level of 3,995 ng/mg creatinine. This baby was diagnosed with "smoker's cough" and admitted to the hospital 2 days after the 4-week home visit. The data collector also watched as the mother put her finger into the baby's mouth as a "pacifier" directly after smoking a cigarette without washing her hands. This outlier was removed from further data analysis. In addition, there was an outlying value in the infant urine nicotine levels at the 6-week data point. This value of 4,190 ng/mg creatinine was also removed from further data analysis. The mother of the infant having this value had just returned from a road trip directly before data were collected. The infant's urinary nicotine level was probably high because both the mother and her boyfriend smoked in the car during the trip.

An additional problem was encountered with urine samples because 27% of the urine samples (4 out of 15) were missing when data were initially collected at birth. This problem was

Table 1
Urinary Cotinine and Nicotine Levels in Inf

Parameter	*M*
Cotinine	
Birth	257.75 ng
2 weeks	231.47 ng
4 weeks	456.4 ng
6 weeks	273.86 ng
Nicotine	
Birth	127.00 ng
2 weeks	313.00 ng
4 weeks	108.73 ng
6 weeks	593.64 n

NOTE: Cotinine and Nicotine are express
gram of creatinine.

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Urinary nicotine and cotinine l
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at 2 weeks (Table 2). The numbe
was strongly related to the infant
weeks of age ($r = .71$, $p < .01$) an
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Table 3 represents the results
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combined to predict infant urin
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When the values for ambient r
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Table 1
Urinary Cotinine and Nicotine Levels in Infants of Mothers Who Smoke

Parameter	*M*	*SD*
Cotinine		
Birth	257.75 ng/mg	191.24
2 weeks	231.47 ng/mg	345.21
4 weeks	456.4 ng/mg	1032.96
6 weeks	273.86 ng/mg	349.35
Nicotine		
Birth	127.00 ng/mg	196.80
2 weeks	313.00 ng/mg	613.59
4 weeks	108.73 ng/mg	217.06
6 weeks	593.64 ng/mg	1136.45

NOTE: Cotinine and Nicotine are expressed in terms of nanograms per milligram of creatinine.

encountered because the newborns often did not urinate during the hour over which the data were collected while in the hospital. As a consequence, some urine collections were left to the staff nurses, who often were not oriented to the study. Once the infants were visited in the home, only 7% (1 out of 15) of the urine samples were missing at 4 and 6 weeks.

Urinary nicotine and cotinine levels were related to maternal smoking behaviors as measured by the cigarette butt collection at 2 weeks (Table 2). The number of cigarette butts collected was strongly related to the infants' urinary cotinine levels at 2 weeks of age ($r = .71$, $p < .01$) and urinary nicotine levels at 2 weeks ($r = .92$, $p < .01$).

Table 3 represents the results of multiple regression analyses when variables reflecting maternal smoking behaviors were combined to predict infant urinary nicotine levels. Only the best combinations that provided the lowest p values for each data collection point were placed in the table.

When the values for ambient nicotine and the scores on the maternal smoking history questionnaire were placed in the model with the number of cigarette butts collected when the infants were 2 weeks of age, the p value remained the same, but 88% of the variance in infant nicotine levels was explained. This increase was 6% more than using the cigarette butt count alone. At the other points in time (4 and 6 weeks), there was not sufficient improvement by combining variables to reach a level of significance. The variation in the degrees of freedom reflects

Table 2
Correlations Between Measures of Exposure and Measures of Absorption (Urinary Cotinine and Nicotine Levels) in Infants of Smoking Mothers Between Urinary Cotinine and Nicotine Levels of Infants of Smoking Mothers and Maternal Smoking Behavior

Parameter	*M*	*SD*	Nicotine *r*	Cotinine *r*
2 weeks				
Nicotine	313.0 ng/mg	196.8 ng/mg		
Cotinine	257.8 ng/mg	191.2 ng/mg		
Score: Smoking Habits Questionnaire	47.6	19.9	.36	0.09
No. of cigarette butts	15.93	13.2	.92*	.71*
Ambient nicotine	2.86 ug/m^3	2.73	.28	.31
4 weeks (outlier removed)				
Nicotine	108.73 ng/mg	217.1 ng/mg		
Cotinine	203.64 ng/mg	342.1 ng/mg		
Score: Smoking Habits Questionnaire	50.52	20.96	.31	−.44
No. of cigarette butts	12.71	5.40	−.000	−.14
Ambient nicotine	2.44 ug/m^3	2.70	−.12	.20
6 weeks (outlier removed)				
Nicotine	317.0 ng/mg	488.3 ng/mg		
Cotinine	273.86 ng/mg	349.4 ng/mg		
Score: Smoking Habits Questionnaire	48	.074	−.11	−.02
No. of cigarette butts	14.79	13.6	.07	.61
Ambient nicotine	3.08 ug/m^3	3.24	.47	.17

*$p < .01$.

several problems with missing data (one urine sample at both 4 and 6 weeks, an outlier removed at 6 weeks, and one cigarette butt collection missing at both 4 and 6 weeks).

Table 4 represents the results of multiple regression analyses when variables reflecting maternal smoking behaviors were used in combination to predict infant urinary cotinine levels. Only the best combinations that provided the lowest *p* values for each data collection point were placed in the table. When the values for ambient nicotine and the scores on the maternal smoking history questionnaire were placed in the model with the number of cigarette butts collected when the infants were 2 weeks of age, the *p* value changed to .0039, and 61% of the variance in infant cotinine levels was explained. This increase was 14% more than using the cigarette butt count alone. When the

Table 3
Multiple Regression Using Ambient Nicoti[...] Predict Infant Urinary Nicotine Levels

	F
2 weeks	36.18*
Cigarette butts	
Smoking habits questionnaire	
Ambient nicotine	
4 weeks	0.95(
Smoking habits questionnaire	
Ambient nicotine	
6 weeks	4.55(
Cigarette butts	
Ambient nicotine	

*$p < .017$.

Table 4
Multiple Regression Using Ambient Nicoti[...] Predict Infant Urinary Cotinine Levels

	F
2 weeks	8.16
Cigarette butts	
Smoking habits questionnaire	
Ambient nicotine	
4 weeks	0.94
Cigarette butts	
Smoking habits questionnaire	
Ambient nicotine	
6 weeks	4.37
Cigarette butts	
Smoking habits questionnaire	
Ambient nicotine	

*$p < .017$.

infants were 6 weeks of age, th[...]
had an adjusted r^2 of 46%, expla[...]
than the single variable of cigar[...]
variation in the degrees of free[...]
data (one urine sample at bo[...]
removed at 4 weeks, and one c[...]
at both 4 and 6 weeks).

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Table 3

Multiple Regression Using Ambient Nicotine and Maternal Smoking Behaviors to Predict Infant Urinary Nicotine Levels

	F	Adj. r^2	Intercept	Slope
2 weeks	$36.18^{*}_{(3, 11)}$	0.8829	−7.095	
Cigarette butts				52.89
Smoking habits questionnaire				−9.46
Ambient nicotine				25.18
4 weeks	$0.959_{(2, 11)}$	−0.0064	−35.28	
Smoking habits questionnaire				−5.56
Ambient nicotine				2.23
6 weeks	$4.550_{(2, 9)}$	.3923	−4.78	
Cigarette butts				3.38
Ambient nicotine				118.18

$^{*}p < .017$.

Table 4

Multiple Regression Using Ambient Nicotine and Maternal Smoking Behaviors to Predict Infant Urinary Cotinine Levels

	$F_{(df)}$	Adj. r^2	Intercept	Slope
2 weeks	$8.16^{*}_{(3, 11)}$	0.6055	236.07	
Cigarette butts				26.57
Smoking habits questionnaire				−9.18
Ambient nicotine				3.22
4 weeks	$0.940_{(3, 9)}$	−.0153	528.43	
Cigarette butts				12.08
Smoking habits questionnaire				−9.26
Ambient nicotine				−13.33
6 weeks	$4.37_{(3, 9)}$	.4572	179.15	
Cigarette butts				21.06
Smoking habits questionnaire				−6.93
Ambient nicotine				42.08

$^{*}p < .017$.

infants were 6 weeks of age, the model using all the variables had an adjusted r^2 of 46%, explaining 15% more of the variance than the single variable of cigarette butt collection. Again, the variation in the degrees of freedom is a reflection of missing data (one urine sample at both 4 and 6 weeks, an outlier removed at 4 weeks, and one cigarette butt collection missing at both 4 and 6 weeks).

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LIMITATIONS

Social desirability may have limited the accuracy of measurement of maternal smoking behavior. Some mothers may have limited their smoking during the 24 hours before data collection. Many women became aware of the discrepancy between how many cigarettes they thought they smoked and how many butts they collected in 24 hours when the first home visit was made (2 weeks). In addition, women in this study were very reluctant to deposit the cigarette butts in the special ashtray as they smoked the cigarettes. Many would put the cigarettes in their own ashtrays and then transfer the cigarettes to the container when the researcher made the home visit to collect data. As the weeks passed, women may have actually saved fewer of the butts while reporting that their smoking had remained the same. Two husbands disputed the number of cigarettes their wives reported smoking. One husband even added two cigarette butts to the special ashtray, saying that he knew his wife smoked more than she had put into the container.

Another possible explanation is that as the mothers became busier and more mobile it became inconvenient to save their cigarette butts. For example, 2 of the smoking mothers had gallbladder surgery during the course of the study, and another had a husband in jail.

As the study progressed, it became apparent that there were many problems with placement of the passive monitors. To prevent nicotine contamination from the mothers' hands, the monitor could not be attached to clothing or moved from room to room. The monitors were placed in the room where the infant spent the daytime hours. Although one would expect that infants of this age would spend most of the day sleeping in a bedroom, this was not the case for the participants in this study. Most infants of smoking mothers spent their days in the living room either on the couch or in a bassinet, so many of the passive air monitors were placed in the living room. Therefore, the monitors absorbed ambient nicotine produced during the day when the infants were there but also in the evening hours when the family might have smoking friends over to visit while the infant was sleeping in a bedroom. In addition, during times of high exposure (e.g., in the car), the monitor was left behind in the living room.

DISCUSSI

THE POPULATION AND SAMPLE

The demographic information ob
ing women in this sample is very s
where (Cunningham et al., 1996
These women were poorer, had le
likely to be married than women

MEASURES OF EXPOSURE

The range in urinary cotinine
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(1991) in North Carolina in 3-
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One would expect the cotinine
because all the mothers smoked
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Cigarette butt collection, a
behavior, was strongly correlat
.92, $p = .0001$) and cotinine lev
infants were 2 weeks of age. Th

DISCUSSION

THE POPULATION AND SAMPLE

The demographic information obtained to describe the smoking women in this sample is very similar to data collected elsewhere (Cunningham et al., 1996; Overpeck & Moss, 1991). These women were poorer, had less education, and were less likely to be married than women who do not smoke.

MEASURES OF EXPOSURE

The range in urinary cotinine levels in this study (0-3,995 ng/mg creatinine) is wider than those found by Greenberg et al. (1991) in North Carolina in 3-week-old infants. Greenberg reported the median cotinine concentration as 79 ng/mg of creatinine with a range of 9 to 643 ng/mg. Only 38% of the mothers in Greenberg's study smoked, however.

One would expect the cotinine levels to be highest at birth because all the mothers smoked during pregnancy. The slight increase in cotinine levels at 6 weeks is consistent with the results of Greenberg et al. (1991), who found an increase in cotinine excretion during the first year of life. By the end of the study, cotinine levels may have increased because two thirds of the infants were now sleeping in the living room during the day, where exposure to ETS was probably the greatest. Marbury et al. (1993) found ambient nicotine levels to be twice as high in the living room than in the child's bedroom. Cotinine is a measure of exposure over several hours, whereas nicotine is a measure of exposure over just minutes. These biomarkers can show considerable variability from person to person due to differences in uptake, distribution, and metabolism (Leaderer, 1990). The results in this study further confirm the considerable variability of nicotine and cotinine levels even in infants who are the same age. When the outliers were removed, the standard deviation for cotinine ranged between 191 ng/mg and 349 ng/mg creatinine, whereas the standard deviation for nicotine ranged between 196 ng/ml to 488 ng/mg creatinine.

Cigarette butt collection, a measure of maternal smoking behavior, was strongly correlated to infant urinary nicotine (r = .92, p = .0001) and cotinine levels (r = .71; p = .0028) when the infants were 2 weeks of age. These results may be attributed to

the design of the study, as discussed in the limitations section. Therefore, cigarette butt collection may be useful just once during the course of a study when the infants are very young. After that, the mothers either may try to manipulate the numbers or become too busy to do the butt collection accurately.

Scores on the smoking habits questionnaire were not related to infant cotinine levels. This may be due to the fact that mothers implemented a variety of "protective" behaviors that were not addressed in the questionnaire. For example, 1 mother smoked under the kitchen stove fan, and 2 other mothers opened windows frequently to air out the house (in the middle of winter) even though they smoked in the same room with the infant. Two women smoked only in the bathroom with the door closed, and 5 smoked in a different "room" of the house that had no door to separate it from the rest of the house. In addition, two infants with parents who had just come back from car trips had cotinine levels that were higher than they had been in the past.

The 24-hour cigarette butt collection proved to be the best predictor of urinary nicotine levels ($p = .0001$) when the infants were 2 weeks of age. This relation did not hold for the following weeks for the reasons discussed previously. When scores from the smoking history questionnaire and ambient nicotine levels are included in the model when the infants were 2 weeks of age, 88% of the variance in infant nicotine levels could be explained instead of 82%. Given the cost of the passive air monitors ($55 per monitor), the cigarette butt collection is the most practical, least expensive, and most accurate method of predicting acute levels of infant exposure to ETS.

Cigarette butt collection again was the best predictor of urinary cotinine levels at 2 weeks. When the other variables—smoking habits questionnaire and ambient nicotine—were placed in the model with cigarette butts, more of the variance in infant cotinine levels was explained by the model. When the infants were 2 weeks of age, 47% of the variance in urinary cotinine was explained by the number of cigarette butts the mother collected in 24 hours. If the scores on the smoking habits questionnaire and the levels of ambient nicotine were also known, one could explain 61% of the variance in urinary cotinine levels. When the infants were 6 weeks of age, much less variance

was explained by these variabl and 46% using all variables).

There was no relation betwee tions collected in the passive a maternal smoking behavior or The 2-week average ambient ni microgram/m^3, and the range w microgram/m^3. These findings Marbury et al. (1993), who foun tion in the bedrooms from th gram/m^3. Although not all moni in the bedroom, it is reassuring were relatively low.

Results from studies vary v among urinary cotinine levels documenting smoking behavior, trations. Although Marbury et al. between ambient nicotine con cotinine levels ($r = .86$) in child Coultas et al. (1990b) determine between these same variables ($r =$ years of age. (They used Spearm describe the relations because t distributed.)

The passive air monitor is desi nicotine concentration (Leadere monitors in this study were used concentration over 14 days. In ad measured in only one room of the be strong for the following reaso sure to ETS within the hours pre rette butt collection lasted 24 ho questionnaire was designed to me relates to the infant. If one were t the future, the results should be c of cigarettes smoked in the hous that the monitor is in place. If p measuring exposure of very small placing the monitor with the infan tant. If one could provide the mo

was explained by these variables (32% using cigarette butts and 46% using all variables).

There was no relation between ambient nicotine concentrations collected in the passive air monitors and measures of maternal smoking behavior or infant urinary cotinine levels. The 2-week average ambient nicotine concentration was 2.7 microgram/m^3, and the range was from nondetectable to 10.5 microgram/m^3. These findings are consistent with those of Marbury et al. (1993), who found average nicotine concentration in the bedrooms from their sample to be 2.7 microgram/m^3. Although not all monitors in this study were placed in the bedroom, it is reassuring that nicotine concentrations were relatively low.

Results from studies vary when searching for relations among urinary cotinine levels in children, questionnaires documenting smoking behavior, and ambient nicotine concentrations. Although Marbury et al. (1993) found strong relations between ambient nicotine concentrations and the urinary cotinine levels ($r = .86$) in children less than 2 years of age, Coultas et al. (1990b) determined that a weak relation existed between these same variables ($r = .15$) for children less than 18 years of age. (They used Spearman's correlation coefficients to describe the relations because their data were not normally distributed.)

The passive air monitor is designed to measure vapor-phase nicotine concentration (Leaderer & Hammond, 1991). The monitors in this study were used to measure average nicotine concentration over 14 days. In addition, the concentration was measured in only one room of the house. The relations may not be strong for the following reasons: cotinine measures exposure to ETS within the hours previous to data collection, cigarette butt collection lasted 24 hours, and the smoking history questionnaire was designed to measure smoking behavior as it relates to the infant. If one were to use the passive monitors in the future, the results should be compared to the total number of cigarettes smoked in the house over the same time period that the monitor is in place. If passive monitors are used for measuring exposure of very small infants, some mechanism for placing the monitor with the infant at all times would be important. If one could provide the mothers with a bassinet for the

baby, moving it from room to room with the baby, it would be ideal. The monitor could be hung on the top of the bassinet, out of sight of curious children, out of the way so mothers would not touch it with nicotine-contaminated hands and with the baby when not being held. Marbury et al. (1993) had good results by placing two monitors in the house with the infant. One was in the bedroom, and the other was in the room the infant spent most hours during the day ("activity room").

IMPLICATIONS FOR NURSING PRACTICE

Although there are very sophisticated (and expensive) ways to measure exposure, one of the simplest and least expensive (24-hour cigarette butt collection) may be the most predictive of levels of exposure. Although results of this study cannot be generalized to the population, there is some evidence that nurses could use this strategy to identify infants at greatest risk for exposure to ETS. Rather than asking the mother how many cigarettes she smokes, asking the mother to collect cigarette butts for 24 hours would be more revealing. The greater the number of cigarette butts collected, the greater the exposure.

RECOMMENDATIONS FOR FUTURE RESEARCH

This study should be replicated. Data collection should be limited to once rather than over time because the data at 4 and 6 weeks were not predictive of exposure to ETS.

Maternal protective behaviors should be explored further and methods to measure the effectiveness of those behaviors refined. For example, if smoking occurs in one room only, does opening a window a crack significantly lower ETS exposure as measured by urinary cotinine? For future studies, the questionnaire should be designed to capture more about how women smoke, what behaviors they engage in to protect their infants from ETS, and if they smoke in the car.

If passive air monitors are to be used to measure ambient nicotine, the procedure must be refined to reflect exposure more accurately. For example, monitors could be placed in multiple locations throughout the home and in the car. It would be even better to design a monitor that could be moved

with the infant (without risk of nico
hands of a smoker).

CONCLUS

The problem of infant exposure
many environmental conditions
level of exposure. The concentrati
smoke depends not only on the n
but on room size, mixing, adsor
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with the infant (without risk of nicotine contamination from the hands of a smoker).

CONCLUSION

The problem of infant exposure to ETS is complex. There are many environmental conditions that have an impact on the level of exposure. The concentration of environmental tobacco smoke depends not only on the number of cigarettes smoked but on room size, mixing, adsorption of smoke components, and the rate of exchange of indoor with outdoor air (Coultas et al., 1990b). In addition, personal exposure varies with the nonsmoker's proximity to the smoker and the time spent in the place where smoking occurs.

This study attempted to develop a model that would predict infant exposure to ETS, a model capable of predicting both acute and chronic exposure to ETS. This led to the conclusion that a 24-hour cigarette butt collection was highly predictive of both types of exposure if done only once. The other measures either alone or in combination with the cigarette butt collection added little to the ability to predict either chronic or acute exposure to ETS. Therefore, in this sample, there was little concurrent validity among the different measures used to assess maternal smoking behavior.

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Commentary

Commentary by Susan P. Shortt

The incidence of maternal smoking in the United Kingdom is estimated to be around 28% (Health Education Authority, 1996). The characteristics of women who smoke during pregnancy appear to be similar to those in the United States, that is, they tend to be young, single women who left school at the earliest opportunity, are unemployed, in manual socioeconomic groups, and have partners who smoke (McNeill, 1998). Only one woman in four manages to stop smoking during pregnancy, and, of those who do quit, two thirds are likely to start smoking again after the birth (Brown, 1998).

It is interesting that despite national campaigns, smoking cessation programs in the United States have been of limited success in relation to women. In England, the position is similar. In 1992, the Department of Health produced a report titled "The Health of the Nation" (Department of Health [DOH], 1992), which proposed that, by the year 2000, a third of pregnant women should stop smoking at the beginning of pregnancy. The Health Education Authority has carried out a series of annual surveys of pregnant women since 1992 and reported that the prevalence of smoking and the rates of stopping or cutting down have changed little over the past 6 years despite

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national initiatives aimed at reducing the incidence of smoking during pregnancy (Owen, McNeill, & Callum, 1998). It was suggested that this may have been due to insufficient investment or lack of prioritization.

Clearly, an immediate priority in health promotion must be to reduce the incidence of smoking during pregnancy, because the harmful effects of maternal smoking on the fetus, and the effect of environmental smoke and passive smoking on the newborn, are well documented. In 1996, however, the Health Education Authority's tracking survey revealed that 61% of pregnant smokers said they had not received any advice about stopping smoking from health professionals (McNeill, 1998). This reported lack of input from health professionals may be related to the attitudes of health care staff toward smoking and the perceived barriers to the promotion of smoking cessation during pregnancy. In two separate surveys, one involving general practitioners, midwives, and obstetricians (Clasper & White, 1995) and the other involving general practitioners, practice nurses, and health visitors (Lennox & Taylor, 1995), health professionals perceived quitting smoking to be difficult and counseling only moderately successful. The majority believed they lacked the skill to counsel effectively and considered that there was little time available to do so and little opportunity to provide continuity of support.

A systematic review of the efficacy of smoking cessation concluded, however, that simple, brief, unsolicited advice from a general practitioner and other psychological interventions such as behavioral techniques were useful to help people give up smoking (DOH, 1998). In the United Kingdom, the regular one-to-one contact that midwives and general practitioners have with women during pregnancy and following the birth provides an ideal opportunity for support and practical advice on giving up smoking. Appropriate training for community-based health professionals, therefore, has become a government priority. Pregnant women who smoke are a key focus of action, and considerable funds have been made available for developing smoking cessation services at the local level so that expert help can be provided where it is most needed (DOH, 1998). It is estimated that savings to the National Health Service can amount to between three and six times the cost of

providing help to pregnant women to give up smoking (Buck, Godfrey, Parrott, & Raw, 1997).

In the United Kingdom, the national charity QUIT, which helps smokers to stop, launched the Pregnancy Quitline in December 1997. With the help of the Health Minister, the project was supported by joint National Health Service and commercial funding. Within this pilot scheme, specially trained counselors provide personal support by means of telephone communication and, with consent, home visits are made to women at intervals throughout pregnancy and following the birth. Relationships are developed over a period of time and the program is tailored to meet individual needs. Within a few months of its launch, the project proved so successful that other local health authorities expressed an interest in funding their own program (Brown, 1998). In North East Wales, the Clywd Smoking in Pregnancy project aims to ensure that help in quitting is available to all pregnant women as part of their prenatal care, as is help to ensure they do not start smoking again in the months after their baby is born. The project includes training for professionals, such as doctors, midwives, and nurses, and structured help for women.

If national campaigns continue to be ineffective, and local initiatives take time to become established and prove their effectiveness, mechanisms for predicting and identifying infants at greatest risk for environmental tobacco smoke-related problems must be developed. With the frequent underreporting of both smoking behavior and the actual number of cigarettes smoked, however, it is difficult to see how this can be achieved. The study aimed at developing a predictive model of infant exposure to environmental tobacco smoke has made some inroads into addressing this problem. A repeat of the study with the suggested adaptations can only prove beneficial in meeting this need.

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